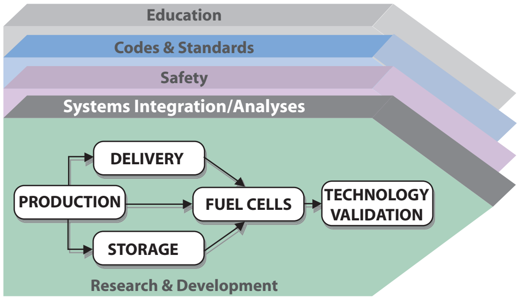
5.0 Systems Integration



Systems Integration provides a disciplined approach to the research, design, development and validation of complex systems, ensuring that requirements are identified, verified and met, while minimizing the impact on cost and schedule of unanticipated events and interactions. Systems Integration supports the Program as it evolves and matures hydrogen production, delivery, storage, fuel cell and supporting technologies through successive stages of research and development. The desired end point is a validated technology set that enables industry commercialization decisions leading to a well-integrated hydrogen system that reliably and cost-effectively provides energy for transportation and stationary applications. The Systems Integrator provides the tools and processes to integrate and measure progress towards the goals of the Program. Tailored to the particular requirements of a robust, long-term research and development program, these tools and processes take advantage of experience and lessons learned from other parts of the federal government (e.g., DOD and NASA) as well as in industry.

5.1 Technical Goal and Objectives

Goal

Establish a disciplined approach that ensures Program requirements are identified, met and validated in the context of dynamic commercial market requirements, while minimizing the impact on cost and schedule of unanticipated events and interactions.

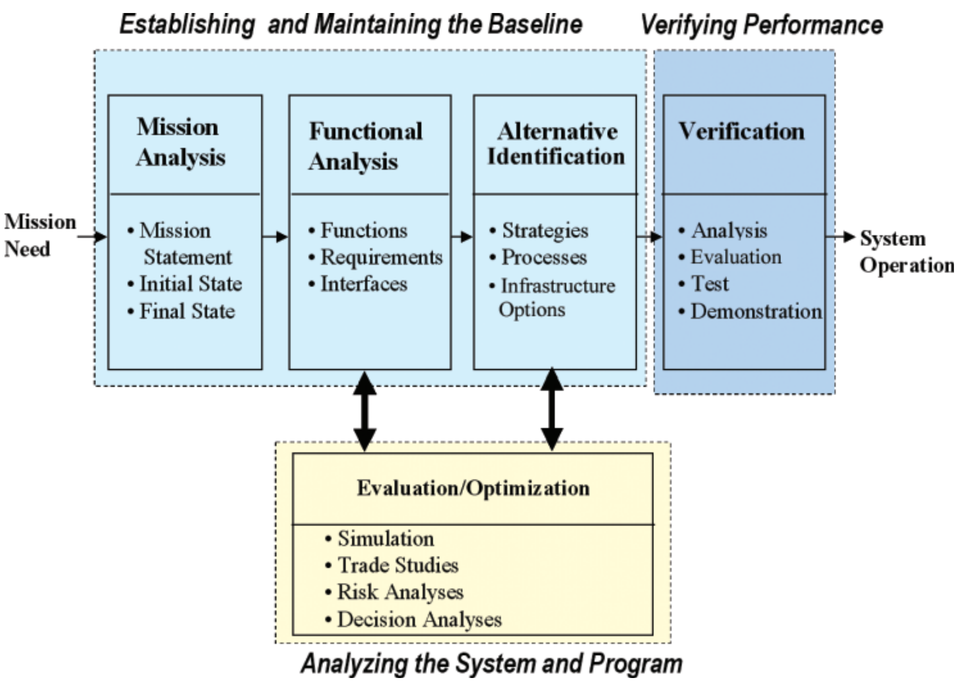
Objectives

- By 2005, establish an integrated technical and programmatic baseline, and maintain and utilize the baseline to support programmatic decisions and ensure research and development directions satisfy needs.
- Verify that the system being developed satisfies the Program requirements, projects are meeting performance and milestone objectives, and progress toward technical targets is substantiated.
- Provide analyses and recommend DOE-sponsored activities to enable the commercial sector to deploy a well-integrated hydrogen system that satisfies needs while continually monitoring system performance to identify potential improvements.

5.2 Technical Approach

Systems Integration provides technical and programmatic support to the Program by 1) establishing, validating, and maintaining the Integrated Baseline as hydrogen technologies and systems are advanced from concept to commercial adoption, 2) providing consistent and independent (when required) results of analyses to support programmatic decisions, 3) verifying that technology and system designs meet Program requirements, and 4) supporting the implementation of strong program engineering and management processes (See Figure 5.2.1).

Figure 5.2.1. Systems Integration Approach Overview

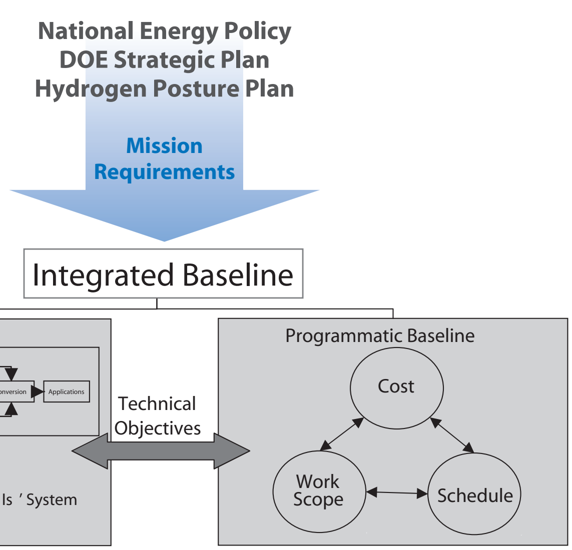


Integrated Baseline

The Integrated Baseline (IB) is a tool and process that helps manage the Program by ensuring that (1) RD&D and analysis projects are properly addressing all of the Program requirements and (2) that the cost, schedule, and performance of the Program and its projects are understood and controlled. In other words, the first ensures that the Program is "doing the right things" and the second that it is "doing things right." These two components are represented by the Technical Baseline (TB) and Programmatic Baseline (PB), respectively, which are then linked by the technical objectives of the Program to provide the "integrated" aspects of the overall baseline. As shown in Figure 5.2.2, the IB is derived from the overarching policy, strategy and planning documents associated with the President's Hydrogen Fuel Initiative. It is a representation of the entire DOE Hydrogen Program funded under that Initiative and is developed and maintained in tools that are readily available, accessible and mature.

Once the IB is approved, it becomes the control version against which the Program is assessed. The Systems Integrator supports the Program in implementing a formal process to manage and control changes to the baseline as budgets are requested and appropriated, as changes in the market or policy context are identified, or as new technical advances and information become available.

Figure 5.2.2. The Integrated Baseline



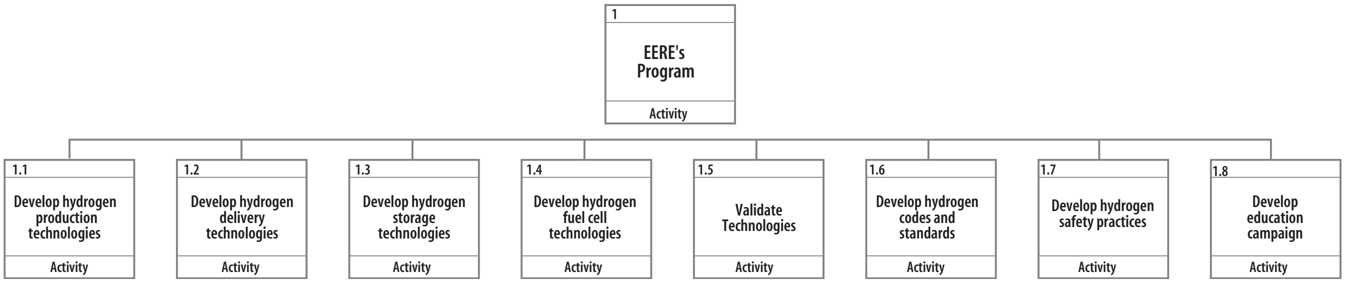
Technical Baseline. In order to ensure that the Program is "doing the right things," the TB provides a detailed mapping starting from the overall requirements, down through the objectives and barriers of the individual Program elements, and finally to the task and individual project level. Requirements for the TB are drawn from the President's Hydrogen Fuel Initiative and related announcements, FreedomCAR and Fuel Partnership Plan, National Energy Policy, National Hydrogen Vision and Roadmap, DOE Strategic Plan, individual DOE Office strategic plans, Hydrogen Posture Plan, DOE Hydrogen Program Management and Operations Plan, and individual DOE Office Multi-Year Research, Development & Demonstration Plans.

The TB includes the prioritization of activities, as well as information on the risk level of individual activities. Questions that can be addressed and answered using the TB include:

- Does the R&D portfolio properly address all the Program requirements?
- Are there gaps or weakness in coverage of technical areas?
- Are the high priority items receiving the proper level of programmatic attention?
- Are there sufficient approaches and projects in the higher risk areas to mitigate those risks?
- When funding or focus changes, in what areas should the Program redistribute, add or decrease resources?

The TB is a complete reference set of technical data describing the current ("as-is") state of the Program and hydrogen infrastructure. The CORE®[1] systems engineering tool (an example CORE graphic is shown in Figure 5.2.3) in which the TB is hosted also has the capability to represent desired ("to-be") end states, in terms of hydrogen infrastructure scenarios or expected descriptions and at different points in time over the next several decades. Using this feature, the TB can be used to identify and evaluate alternative pathways for meeting the needs/requirements or responding to a new transition period or to long-term infrastructure directions.

Figure 5.2.3. Example of TB Representation from CORE



The process of reviewing and validating requirements and aligning the Program with those requirements is recurrent to accommodate advances in R&D, as well as changes that result from the evolution of markets or policies, budget changes or programmatic focus.

Programmatic Baseline. To ensure that the Program is "doing things right," the PB provides a tool and process to track the cost, schedule, and performance of the Program down to the individually funded projects (Figure 5.2.4). The PB describes these efforts in terms of their budget, milestones, and scope, and identifies the dependencies among the activities through an integrated work breakdown structure and master schedule. Loaded with the resources necessary to accomplish the work (funding, personnel, tools, facilities, etc.), it allows assessment of shortfalls and effects of shifting priorities or funding changes. Questions that can be addressed and answered using the TB include:

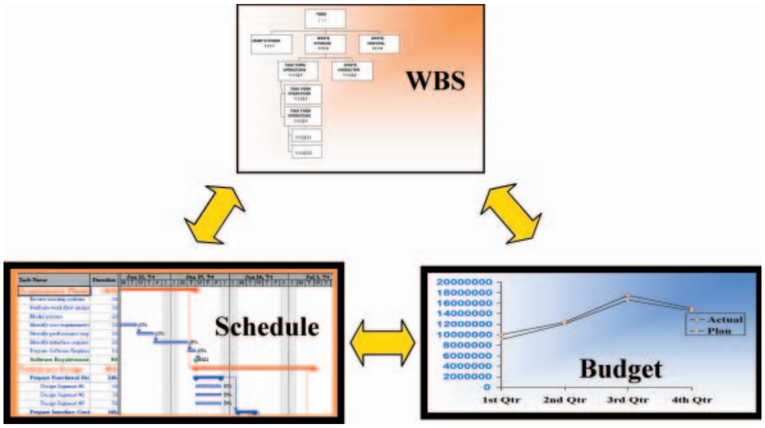
- Are budgets and schedules on track – for the Program, a Program element, a task or an individual project?
- If there is a delay in a particular activity's schedule, what is the cost and schedule impact on dependent or related activities?
- If funding is reduced in an area, what is the impact to the schedule, and if resources are reallocated, how are schedules affected?
- How does the Program scope change given different funding-level scenarios?

[1] CORE® is a registered trademark of Vitech Corporation.

Systems Analysis

Systems Integration supports the review and assessment of alternatives for satisfying the needs of the future hydrogen system/economy and the Program's progress. In addition, Systems Integration provides independent analysis, when required, to help ensure objective and substantiated decisions by the Program. For example, when key Program decision milestones are approached, Systems Integration convenes technical review panels of peer experts to provide an independent recommendation to DOE for consideration during the decision process.

Figure 5.2.4. Programmatic Baseline Concept



Technical Performance Verification

As the Program develops technologies and results, Systems Integration facilitates technical reviews at key stages to evaluate strategic fit with Program objectives, technical potential, economic/market potential, and environmental, health, and safety considerations along with the plan for further development. Verification will be accomplished through analysis, testing and/or demonstration. Criteria and approaches will vary depending on the maturity of the technology. For example, at early stages of development, information available to evaluate concepts is likely to be more general and have higher uncertainty than that available at later stages. Information stemming from these reviews will be used to re-evaluate the baseline.

The Systems Integrator works closely with the DOE Technology Development Managers to bring knowledge of system-level requirements and review criteria to planning and execution. In particular, the Systems Integrator supports reviews of the following Program activities:

- Peer review for all projects and activities
- Independent review panels for key Program milestones and Go/No-Go decisions
- Stage Gate reviews at key progress points for significant projects

Management and Technical Support

Systems Integration supports the Program by aiding implementation of several key processes, two of which are described below:

Risk Management. Systems Integration supports implementation of a risk management process to identify potential Program risks and determine actions that will mitigate the impact of those risks. A six-step risk process—risk awareness, identification, quantification, handling, impact determination, and reporting and tracking—is used. Throughout the life of the Program, the System Integrator helps identify "potential" risks, focusing on the critical areas that could affect the outcome of the Program such as:

- System Requirements
- Environment, Safety and Health
- Modeling and Simulation Accuracy
- Technology Capability
- Budget and Funding Management
- Schedule
- Stakeholder, Legal and Regulatory Issues

Configuration Management. Systems Integration manages the evolving configuration of the hydrogen system (i.e., the Technical Baseline) and continuously monitors and controls it during its life cycle. Changes to the Technical Baseline and the Programmatic Baseline (the approved work scope, schedule and cost) must both be controlled to ensure that all work being performed is consistent with the approved technical requirements and the current configuration, and that impacts throughout the Integrated Baseline are considered before actions are taken. A formal change control process has been established to ensure that the potential impacts of proposed changes to either the Technical Baseline or the Programmatic Baseline are evaluated, coordinated, controlled, reviewed, approved and documented in a manner that best serves the Program and its projects. The decision-making body within the Program for approving proposed changes is the Change Control Board. The procedures and processes will be documented in a Configuration Management Plan.

5.3 Programmatic Status

Table 5.3.1 provides the current set of Systems Integration tasks and activities.

Table 5.3.1. Current Systems Integration Activities

Activities	Description
Integrated Baseline	• Technical Baseline: Using the results of the mission and functional analyses, link and map the various levels and aspects of the Program – requirements, tasks, objectives, barriers, technical targets and projects. • Programmatic Baseline: Assemble the necessary data on subprogram and individual project cost, schedule, work scope and interdependencies.
Systems Analysis	• Develop the Systems Analysis Plan • Define requirements for the Macro-System Model • Initiate Data Book development activities • Support the Technology Analyst in technical management and monitoring of analysis projects • Coordinate cross-cutting activities and plans for critical analyses (e.g., hydrogen purity/quality)
Verification of Technical Performance	• Conduct program peer review at Annual Merit Review Meeting • Tailor stage gate review process to fit Program needs and context • Choose and acquire resources to perform independent assessment of progress on key technical targets
Management and Technical Support	• Develop the Configuration Management Plan • Develop the Risk Management Plan

5.4 Technical Challenges

The following discussion details the various technical and programmatic barriers that must be overcome to attain the DOE Hydrogen Program Systems Integration goal and objectives.

Barriers

A. Integrated Baseline Development and Utilization. The breadth and depth of the DOE Hydrogen Program make it a challenge to encompass all aspects into the Integrated Baseline. Completeness is important, because a true assessment of the sufficiency of program efforts against the requirements can only be made if the entire Program is represented. The four DOE offices (EERE, FE, NE and SC) and other programs and agencies (e.g. Department of Transportation) that are involved in work under the President's Hydrogen Fuel Initiative each have their own baselining and scheduling requirements, which must be consistent down to the individual projects. Tracking and assessing progress requires that projects have meaningful milestones, along with periodic reviews and/or reports to allow transparency in terms of accomplishments and progress. The Integrated Baseline can only provide value if it becomes an accepted and utilized tool for the planning and decision-making processes within the Program.

B. Systems Analysis. Analysis at the hydrogen system level will require modeling tools that do not currently exist. The integration of existing unique models into the Macro-System Model will require hydrogen community support and sufficient resources to develop, maintain and grow the model. For example, relating the Macro-System Model to existing national energy infrastructure models used for market and benefits analysis (e.g. NEMS and MARKAL) must be addressed.

C. Verification. The primary barrier in verification of technical performance is purely one of numbers and time/resources. For example, in FY05, the Program is funding over 200 RD&D and analysis projects to address approximately 250 technical targets. The time and resources needed to verify the progress, status and results of all these activities is a challenge.

D. Processes. Systems integration and engineering practices have typically been applied to large hardware acquisition projects, not necessarily to R&D programs. Tailoring the systems integration procedures and tools to the R&D paradigm will be a challenge, as will be gaining Program and stakeholder acceptance of these processes as value-added and important to Program element and overall Program success.

5.4.1 Expected Outcomes

Establishing standardized tools and approaches to identify, document and evaluate the complex interactions between components, systems costs, environmental impacts, societal impacts and system trade offs will enable effective management of the Program and evaluation of alternative concepts and pathways, and result in well-integrated and optimized hydrogen and fuel cell systems. Over the course of the President's Hydrogen Fuel Initiative, Systems Integration will enable the Program to:

- Establish well-documented system requirements linked to Program objectives
- Ensure that technology designs meet requirements
- Provide consistent systems-level analyses
- Make and document defensible decisions
- Identify and manage risk

5.5 Technical Task Descriptions

The technical task descriptions are presented in Table 5.5.1.

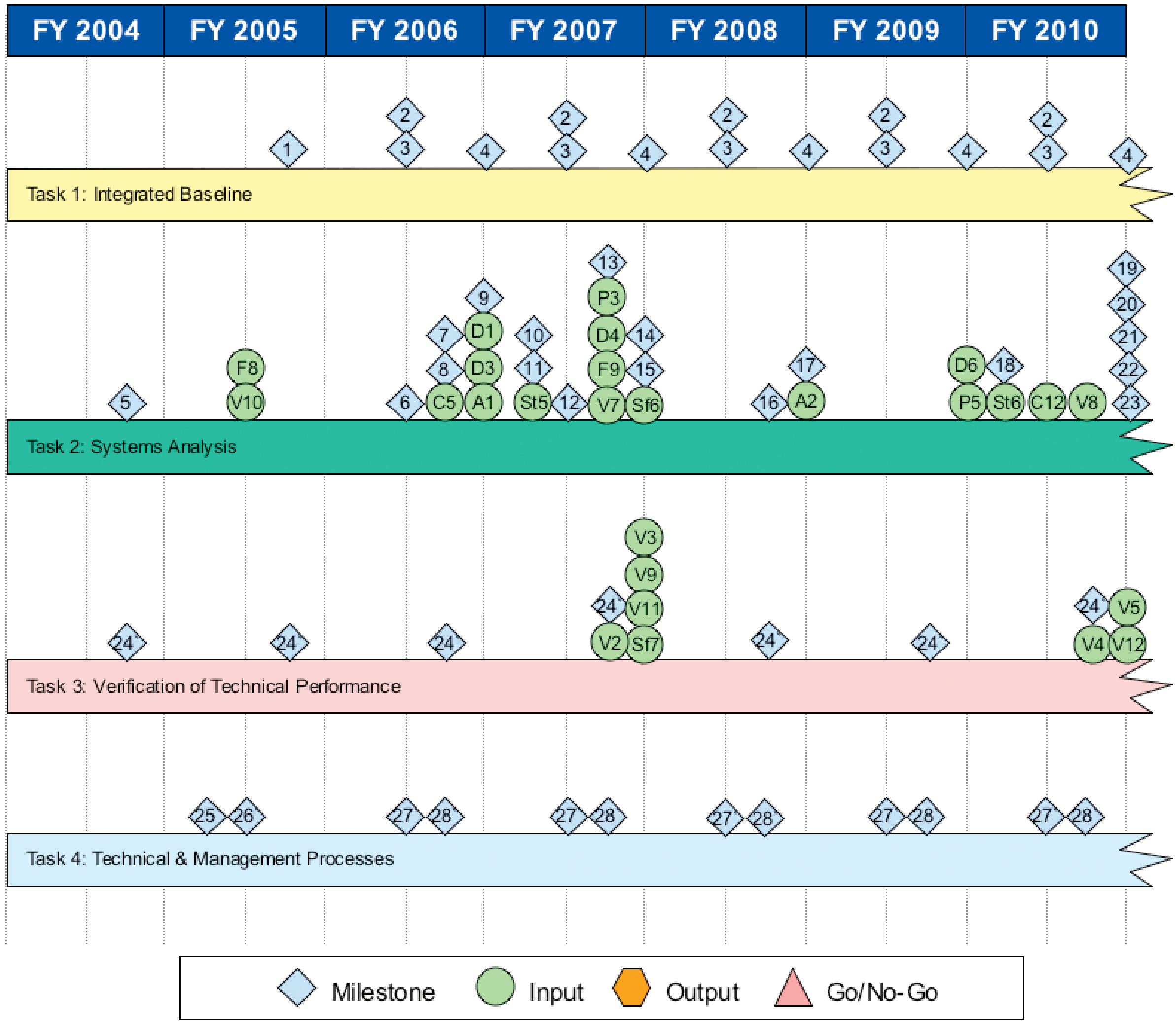
Table 5.5.1. Technical Tasks

Task	Description	Barriers
1	**Integrated Baseline** • Finalize all the inputs to the Technical Baseline and the Programmatic Baseline • Determine risks and priorities and integrate them within the key tasks and milestones of the baseline • Validate the baseline through each of the Program technical and cross-cutting elements • Complete independent quality assurance review of the baseline for accuracy and completeness • Place the Integrated Baseline under configuration management and formal change control • Produce periodic updates to the baseline as required	A
2	**Systems Analysis** • Develop the Analysis Portfolio • Develop, maintain and resolve consistent data sets/info and standard analysis assumptions and guidelines • Provide independent analysis (policy-related issues, Go/No-Go recommendations, H_2 in the context of larger energy markets, etc.) • Ensure tools/models are developed, maintained, available and validated • Provide independent review of analysis results • Support the definition of analysis scenarios	B
3	**Verification of Technical Capability** • Conduct the peer review process in conjunction with the Annual Merit Review Meeting (including EERE, FE, NE, and SC projects) • Provide independent verification of the status and progress toward key technical targets of the Program • Implement the Stage Gate review process for critical projects across the various Program elements	C
4	**Technical and Management Processes** • Complete the Configuration Management Plan and implement its processes within the Program • Support the Change Control Board • Complete the Risk Management Plan and implement its processes within the Program • Support the Risk Management Board	A, B, C, D

5.6 Milestones

Figure 5.6.1 shows the interrelationship of milestones, tasks, supporting inputs from other Program elements and outputs from the Systems Integration function from FY 2005 through FY2010. This information is also summarized in Table B.10 in Appendix B.

Figure 5.6.1. Systems Integration R&D Milestone Chart



For chart details see next page.

Milestones

1 Approval of initial Integrated Baseline.
2 Integrated Baseline updates based on actual FY06 through FY10 Program appropriations.
3 Integrated Baseline versions reflecting FY08 through FY12 budget requests.
4 Integrated Baseline updates based on FY07 through FY11 spend plans.
5 Independent analysis for Fuel Cells Go/No-Go decision on fuel processing R&D.
6 Independent analysis for Fuel Cells Go/No-Go decision on sensors and controls technologies.
7 Independent analysis for Fuel Cells Go/No-Go decision on MEA in single cell meeting targets.
8 Supporting analysis for Systems Analysis production and delivery task.
9 Independent analysis for Tech Val Go/No-Go decision on purchase of additional vehicles .
10 Independent analysis for Storage Go/No-Go decision on compressed and cryogenic tank technologies for on-board.
11 Independent analysis for Storage Go/No-Go decision on carbon nanotubes.
12 Independent analysis for Production Go/No-Go decision on continued high-temperature steam electrolysis R&D.
13 Independent analysis for Fuel Cells Go/No-Go decision on air management and thermal management technologies.
14 Independent analysis for Production Go/No-Go decision on membrane separation technology.
15 Independent analysis for Fuel Cells Go/No-Go decision on scale up precious metal reclamation process.
16 Supporting analysis for Systems Analysis hydrogen purity task.
17 Independent analysis for Fuel Cells Go/No-Go decision on auxiliary power, portable power and off-road R&D.
18 Independent analysis for Storage Go/No-Go decision on advanced carbon-based materials.
19 Independent analysis for Storage Go/No-Go decision on continuation of on-board reversible metal hydride R&D.
20 Independent analysis for Storage Go/No-Go decision on chemical storage R&D for 2015 targets.
21 Independent analysis for Fuel Cells Go/No-Go decision on stationary fuel cell systems.
22 Independent for Production Go/No-Go decision for transparent H_2-impermeable material.
23 Independent analysis for Production Go/No-Go decision on high-temperature solar-driven thermochemical cycles.
24 Conduct peer review of projects at Annual Merit Review.
25 Formal configuration management plan approved and processes implemented.
26 Formal risk management plan approved and processes implemented.
27 Change Control Boards periodically each fiscal year.
28 Risk Management Boards periodically each fiscal year.

Inputs

F1 Input from Fuel Cells: Critical analysis of well-to-wheels studies of fuel cell system performance, efficiency, greenhouse gas emissions, and cost.
F8 Input from Fuel Cells: Preliminary hydrogen purity/impurity requirements.
V10 Input from Technology Validation: Hydrogen refueling station analysis - proposed interstate refueling station locations.
C5 Input from Codes and Standards: Completed hydrogen fuel quality standard as ISO Technical Specification.
D1 Input from Delivery: Assessment of cost and performance requirements for off-board storage systems.
D3 Input from Delivery: Hydrogen delivery infrastructure analysis results.
A1 Input from Systems Analysis: Complete technoeconomic analysis on production and delivery technologies currently being researched to meet overall Program hydrogen fuel objective.
St5 Input from Storage: Baseline hydrogen on-board storage system analysis results including hydrogen quality needs and interface issues.
P3 Input from Production: Impact of hydrogen purity on cost and performance.
D4 Input from Delivery: Assessment of impact of hydrogen purity requirements on cost and performance of hydrogen delivery.
F9 Input from Fuel Cells: Updated hydrogen purity/impurity requirements.
V7 Input from Technology Validation: Final report on infrastructure and hydrogen quality for first generation vehicles.
Sf6 Input from Safety: Sensor meeting technical targets.
A2 Input from Systems Analysis: Initial recommended hydrogen quality at each point in the system.
P5 Input from Production: Impact of hydrogen purity on cost and performance.
D6 Input from Delivery: Update of hydrogen purity/impurity requirements.
St6 Input from Storage: Final on-board hydrogen storage system analysis results of cost and performance (including pressure, temp, etc) and down-select to a primary on-board storage system candidate.
C12 Input from Codes and Standards: Final hydrogen fuel quality standard as ISO Standard.
V8 Input from Technology Validation: Final report on infrastructure, including impact of hydrogen quality for second generation vehicles.
V2 Input from Technology Validation: Final report for first generation vehicles and interim progress report for second generation vehicles, on performance, safety, and O&M.
V3 Input from Technology Validation: Technology Status Report & re-focused R&D recommendations.
V9 Input from Technology Validation: Final report on safety and O&M of three refueling stations.
V11 Input from Technology Validation: Composite results of analyses & modeling from vehicle and infrastructure data collected under the learning demonstration project.
Sf7 Input from Safety: Final peer reviewed Best Practices Handbook.
V4 Input from Technology Validation: Final report for second generation vehicles on performance, safety, and O&M.
V5 Input from Technology Validation: Technology Status Report & re-focused R&D recommendations.
V12 Input from Technology Validation: Final composite results of analyses & modeling from vehicle and infrastructure data collected under the Learning Demonstration Project.